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Route Optimisation for Muncipal Solid Waste Collection using ArcGIS Application in Gwalior City, Madhya Pradesh

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Abstract: ***Uncontrolled growth of the urban population in developing countries in recent years has made solid waste management important issues, so the system for collection of solid waste thus constitutes an important component of an effective solid waste management system. In present study an attempt is made to design and develop an appropriate collection plan by Geographical Information System (GIS) software for the selected wards at Gwalior, in Madhya Pradesh, India and also demonstrate the significant reduction in time that can be obtained compared with the current practices in the study area .The city limits of Gwalior were extended from 177.3 to 423.4sq km in 2016, leading to sub-optimum levels in solid waste transportation of 401tonnes per day. After developing a spatial database for the whole of Gwalior with 66 wards, the route optimization procedure have been run for the transport of solid waste from 10 wards to one transfer station (intermediary before landfill), using ArcGIS. The network analyst tool available in ArcGIS is used to find the optimized route for solid waste collection considering all the required parameters for solid waste collection efficiently. These parameter include the position of solid waste collection routes, road network, the population density, waste collection schedules, truck capacities and there characteristics. A GIS optimal routes model was designed for efficient collection path for municipal solid waste to minimum time, less fuel, shortest travel path and outline the workflow and best practices for future analysis throughout the city. The overall savings are thus very meaningful for the entire Gwalior.***

Keywords: ArcGIS10.4.1 version, Geographical Information system, route optimisation, Network Analyst, Solid Waste Management, transportation and Waste collection.

I. INTRODUCTION

Solid waste generation by the daily activities of the people needs to be properly managed in such a way that it minimizes the risk to the environment and human health. Inadequate collection and disposal of solid waste is a major factor in the spread of disease and environmental degradation. One of the most visible problems in the provision of solid waste management (SWM) is the collection route developed and save the cost of fuel and time of service of the solid waste.

The Municipal Corporation of Gwalior spends nearly 50% of its total expenditures on collection of solid waste, 30% on transportation and 20% on final disposal arrangement. There are some wards in Gwalior where door-to-door facilities were not provided. Solid waste management is undoubtedly an increasingly important element in term of efficiency and profitability for any municipality. Therefore, optimizing of collection services is still depending on the knowledge of local conditions such as one-way street and road construction by the collection teams. The problems encountered during collection are:

1) Variation of waste production over time
2) Large extension of area to be served
3) Traffic and viability conditions
4) Labor cost
5) Poor routing system.

A. Objective

The objective of present study is to arrive for collection of Municipal Solid Waste in Gwalior with recourse to GIS.

1) To determine the optimum route for solid waste collection and disposal.

B. Gwalior And Solid Waste

Gwalior is located at (Latitude: 26° 13' 25N, Longitude: 78° 10' 45 E) and its falls in zone 44N. It has an average elevation of 197 meters (646 feet). It is an historic Indian city located on the periphery of Madhya Pradesh. It occupies a strategic location in the Gird region of India, and the city and its fortress have served as the centre of several of historic northern Indian kingdoms. That the location of the city still is considered militarily important is signaled by the presence of a major air force base at Maharajpura. According to Census 2016, the population of Gwalior city with 4 vidhansabha, 25 zones and 66 wards with population 1159032 and the household 2211842.

Gwalior is bounded by districts of Morena, Bhind, Sheopur, Shivpur and Datia on its north- west; north-east, south-west, south and east respectively. Its headquarters located at Gwalior city which is administered by Gwalior Municipal Corporation and is well connected to all major towns and cities through Roadways, Railways and Airways.

Solid waste management is the one of the major activities of the CoC. This process is however, very tedious as it involves collection of garbage generated at every house through various means and then moving the wastes to the two disposal sites or dumping yards. All of the 66 city wards are estimated to generate about 401 tonnes of garbage a day. The high moisture content in the solid waste 42.67%.It is estimated that the annual per capita growth rate for MSW generation is 2.33%.

C. The Solid Waste Flow And Current Network

Over 3400 workers are engaged in the sweeping, collection of waste, managing and operating the transport operations in the MSWM of GMC.Of the total work force, as many as 1300 manually sweep all the roads of the city and work with collection of waste from waste bin/litter bins. The Corporation employees are engaged in sweeping the streets at least once a day, using brooms, brushes, wheel bins, wheel barrow and also long brooms. The sweepers between 6am to 11am carry out street sweeping. The collected wastes are dropped into the waste bins along the streets, placed at regular interval. The average road length per sweeper is 500 km, the labour is provided with 25 trolleys and 750 hand carts. No prescribed routes have been following yet. The solid waste are collected by workers in each of 66 wards by door-to door collection and then transported to transfer station and then to dumping yards. The wastes from some wards were directly moved to dumping yard because there transfer stations were in under constructions. The diagram is self –explanatory. The architecture of MSWM shows clearly the four components of SWM system, generation, collection, transport and disposal. The generation of waste from residences, hostels, malls, complexes and street. The street waste were collected by litter bin with capacity 100 litter which were manually sweep by sweepers in morning between 6am to 8am.The residential waste were collected by tri cycle or auto tipper with capacity 0.8-1 tones. They moved to transfer station by auto tipper or light motor vehicles and then from there to dumping site using heavy motor vehicles and light motor vehicles.

II. STUDY AREA

The study area is consisting of 10 wards having area of 13.334km² with household 34454 and population 18665, involving one transfer station. These 10 wards generate 64.7 tonnes of garbage daily (16% of total Gwalior garbage).The ward-wise tonnes that are moved daily to transfer station and the distance travelled are given in table 1.The transfer station handle the entire 64.787tonnes daily and transports the garbage using multi-axle vehicle to dumping yard at Kedarpur, Shivpuri link road. The existing road network of the study area covering all the 10 wards and the transfer stations. They involves42 vehicles (auto tipper), 2 compacter, 4 hook loader by which they carry the garbage daily including 50 drivers and 50 helpers. The auto tipper collects 750 house hold waste and then return to transfer station they follow this processes for collecting wastes.

Figure 1.GMC: zones,transfer station, wards

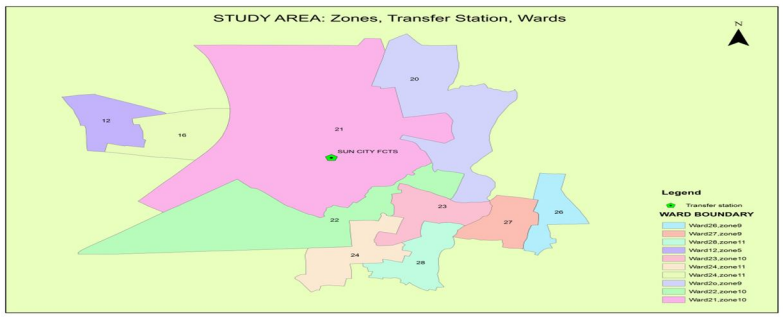


Table 1. Distance and garbage transported daily from 10 wards attached to transfer station.

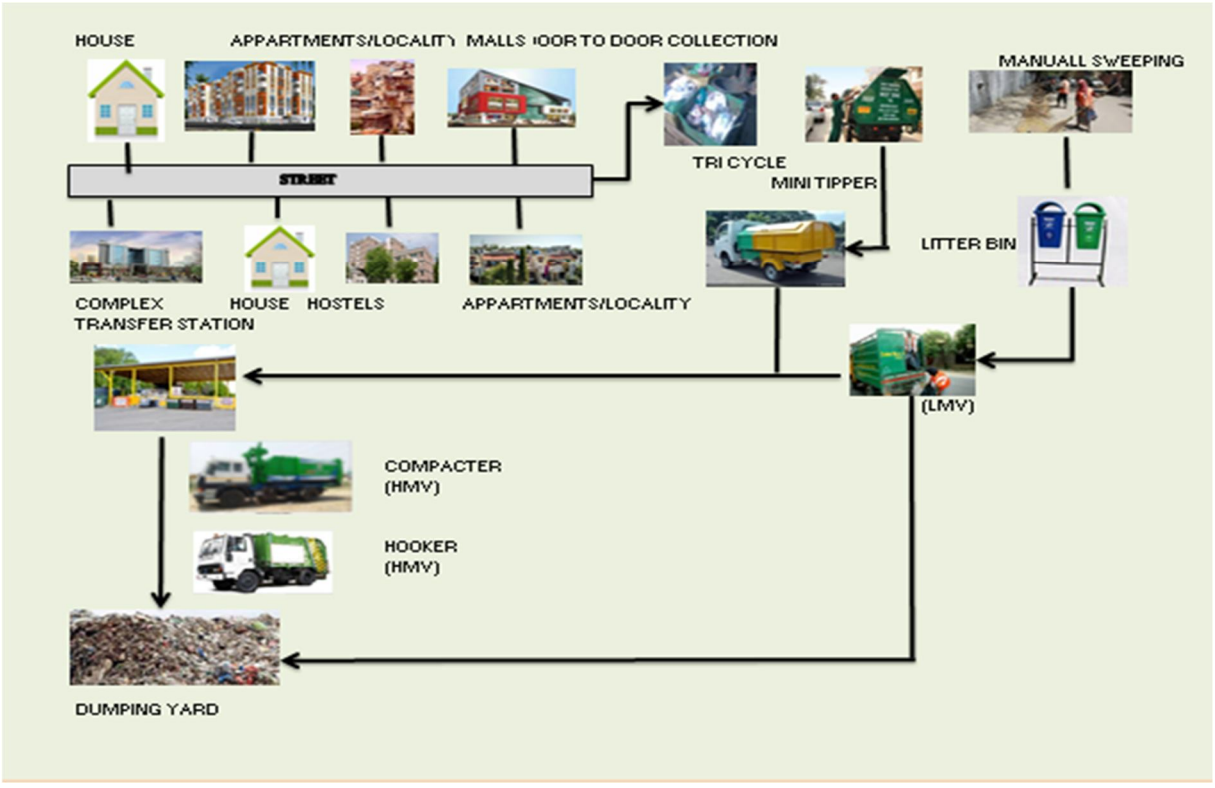
ward no.	Garbage (tonnes per day)	Current distance (km)
12	4.77	16.785
16	4.16	18.362
20	10.857	47.346
21	8.369	99.3013
22	8.385	44.981
23	7.505	22.096
24	2.526	18.813
26	5.577	17.382
27	5.322	15.884
28	7.307	24.381
Total	64.778	

A. Why GIS?

GIS is software, designed to allow users to collect, manage, analyses and retrieve large volume of spatially referenced data and associated attribute data collected from a variety of sources. GIS enable the readers to visualize, and interpret data for a better understanding of relationships, trends and patterns. It also improved SWM programs. The routing solver within the ArcGIS network analyst, namely, the route is based on the Dijkstra Algorithm, which solve the single source, shortest path problem.

The primary data comprised different map layers of the study area. The layers are boundary (base map), road network, ward location, Transfer station location and dumping yards. The primary data consist of both spatial and attribute information.

Figure 2: Architecture of solid waste management: GMC (LMV, light motor vehicle; HMV, heavy motor vehicles)



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III. METHODOLOGY

A. Data collect

For generating the optimal routes for the solid waste collection of Gwalior city, the following data were collected:-

S. NO.	Data type	Source
1	Study area boundary	GMC
2	Satellite imagery of area	Google earth
3	Road network and their names	GMC and Google earth
4	Ward wise population and house hold	GMC
5	locality and locations	Google earth
6	characteristics of waste	GMC
7	type of vehicles used and its capacity	GMC
8	Collection of solid waste per wards	GMC
9	Existing run routes for the tipper and compactor	GMC

Table 2. Collected data type and their respective source

B. Digitization

The Gwalior city map were scanned .The scanned image was digitized by using ArcGIS 10.4.GIS can be used to store geographic data, make maps and analyze spatial data. The image was then geo-referenced by transferring to the file creating a raster. With the help of tool box we can convert the files. The raster was then digitized which involves conversion of raster into vector by creating shape file of point, line and polygon representing location. The digitized file will be in the .shp format. The map data organized into layers, so that we can choose which layer we want to view or query. ArcGIS is produced by environmental system research institute (ESRI).

C. GIS Analysis

In GIS analysis we check the route connection and remove the errors which were found in study boundary and in road networks. Errors like intersect, gaps, overlap, presudo nodes, dangles etc. which were removed. The road network consists of three layers, which is represented as different line feature on the map. The network data set has been created from multiple feature classes that include simple features within a feature dataset. The new mxd will contain the all layers and file in one themes.

D. Adding Attribute

Non spatial data such as road name, speed limit, road type, ward name, ward no, zone no, and distance, directions etc. were added.The speed limits of the collection vehicles are 2km/hrs. in arterial road, 5km/hrs. in main road and 50km/hrs. in major road as per the interview of driver.

E. Route Generation

The topology checks are done to identify the missing links on all available routes. The ArcGIS is applied by giving the starting pickup point and the ending pickup point by which the algorithm identifies the path. The optimum route was generated using Network Analyst, an extension of ArcGIS 10.4.

F. Network Analyst

The main objective was to minimize the total collection distance. This in turn would automatically reduce the collection time. Network analyst can solve common network problem. The algorithm identifies the shortest path and provides the same on a GIS map, along with route distance.

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IV. RESULT

For this research, only a part of the GMC area was taken, measuring 13.33km² involving 10 wards and one transfer station. The GIS provided all the available road connectivity between all the required points. After applying ArcGIS, by giving the starting pickup point in the ward one by one so they get the route direction and the ending pickup point in all the wards, the algorithm identified the shortest path and provided the same on a GIS map, along with rout distance. The ArcGIS- generated optimized routes were compared with the current routes for all of the 10 wards. For each ward the current route length is tabulated with the ArcGIS optimized routes length and the details are given for each link in table3. The comparison of the current and ArcGIS route distance generate a saving of 31.25% of the haul distance and the reduction in weighted average tonne-km is 33.05%. The comparison of the current and ArcGIS roué time generate a saving 31.32%.

As per the GMC department the average speed of auto tipper vehicle is 2km/hr.as door-to-door for solid waste collection. The digitized maps giving the current and computed route are given for the selected wards where there is relatively major difference between the current route distance and optimal or ArcGIS route distance .The route maps for the wards 23and 27 are given in the figure 3 and 4.

Table 3.Current distance versus ArcGIS route [shortest path] distance (km).

Ward	Garbage (tonnes per day)	Current distance (km)	ArcGIS distance (km)	Savings in distance(km)	Saving in km (%)	Savings in tonne-km per day	Current tonne-km	Saving in tonne-km (%)
12	4.779	16.786	10.877	5.909	35.20	28.23	80.22	35.19
16	4.16	18.362	9.139	9.223	50.22	38.36	76.38	50.22
20	10.857	47.36	26.020	21.34	45.05	231.68	514.18	45.05
21	8.369	99.302	64.120	35.182	35.42	294.43	813.05	35.42
22	8.385	44.981	37.556	7.425	16.50	62.25	377.16	16.50
23	7.505	22.099	19.819	2.28	10.31	17.11	165.85	10.31
24	2.526	18.819	12.693	6.126	32.55	15.47	47.53	32.54
26	5.577	17.382	11.084	6.298	36.23	35.12	96.94	36.22
27	5.322	15.895	13.103	2.792	17.56	14.85	84.59	17.55
28	7.307	24.386	19.258	5.128	21.02	37.47	178.18	21.02
Total	64.787	325.372	223.669	101.703	31.25	810.61	2452.08	33.05

Table 4. Current time versus ArcGIS route (shortest path) time hours.

Ward No.	Current distance (time)in hours	Optimized distance (time) in hours	saving in time	Saving in time (%)
12	5.847	3.789	2.058	35.19
16	7.60	3.783	3.817	50.22
20	15.39	8.459	6.931	45.03
21	31.37	20.255	11.115	35.43
22	13.50	11.261	2.239	16.58
23	9.42	8.451	0.969	10.25
24	7.05	4.757	2.293	32.52
26	6.44	4.109	2.331	36.19
27	4.62	3.809	0.811	17.55
28	8.20	6.481	1.719	20.96
total	109.437	75.154	34.283	31.32

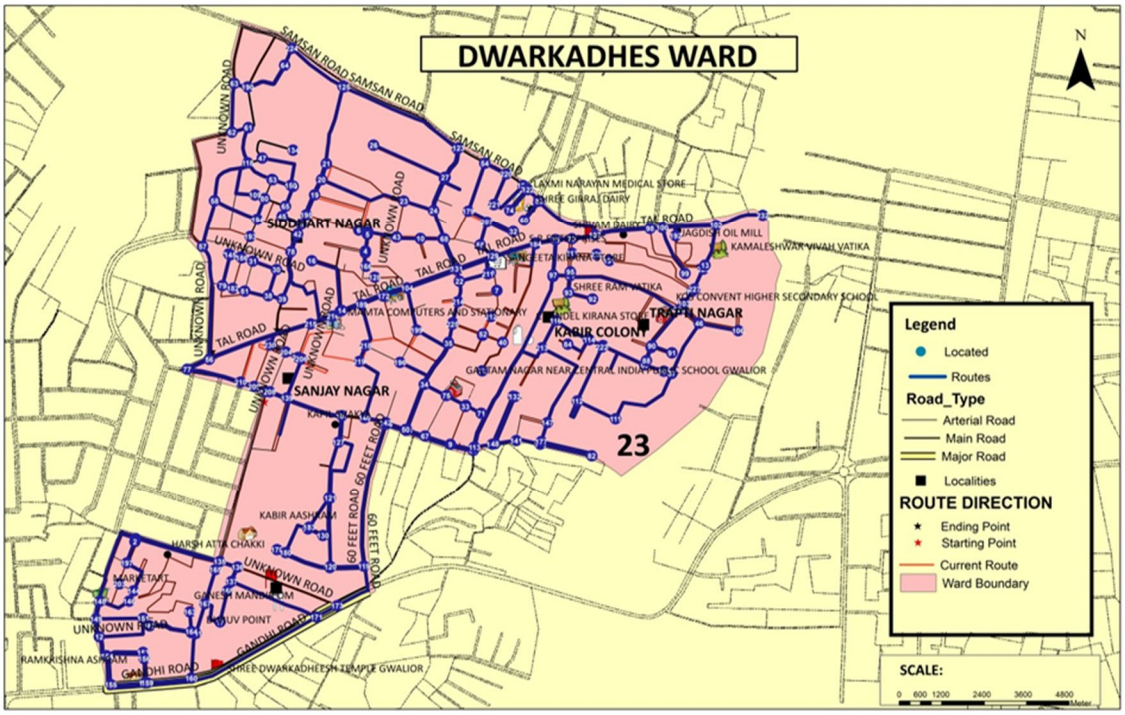

Figure 3: current route versus optimum route for ward 23.

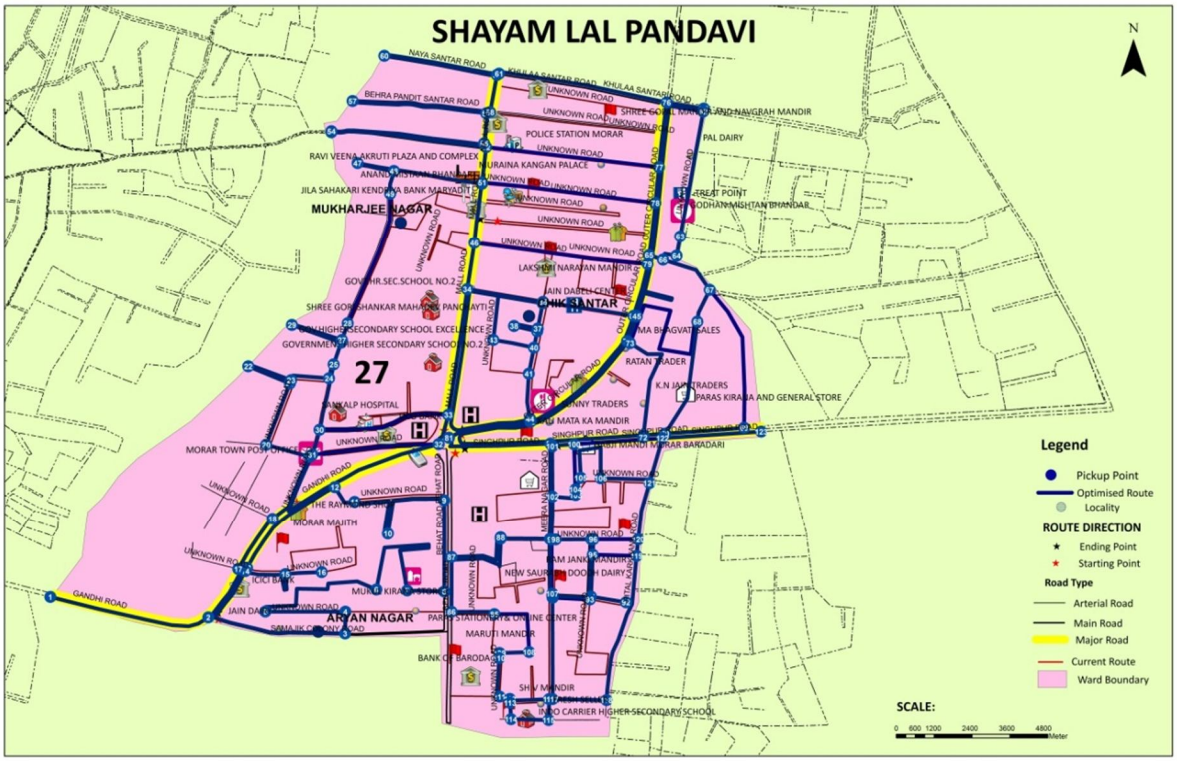

Figure 4: current route versus optimum route for ward27.

V. CONCLUSION

In the present study an attempt has been made to optimize the solid waste route for vehicle in Gwalior city by using ArcGIS Network Analyst. With the GIS technique , optimum route was identified which found less time consuming and short distance when compared with the existing run route. The GIS application was used for identifying the optimum route for 10 wards out of total of 66 wards. They need to be carried out for all the 66 wards of the GMC to achieve maximum saving of time for city as a whole, and to every major city in the world. The optimization method for determining the optimum route could be used by the corporation authorities to improve management.

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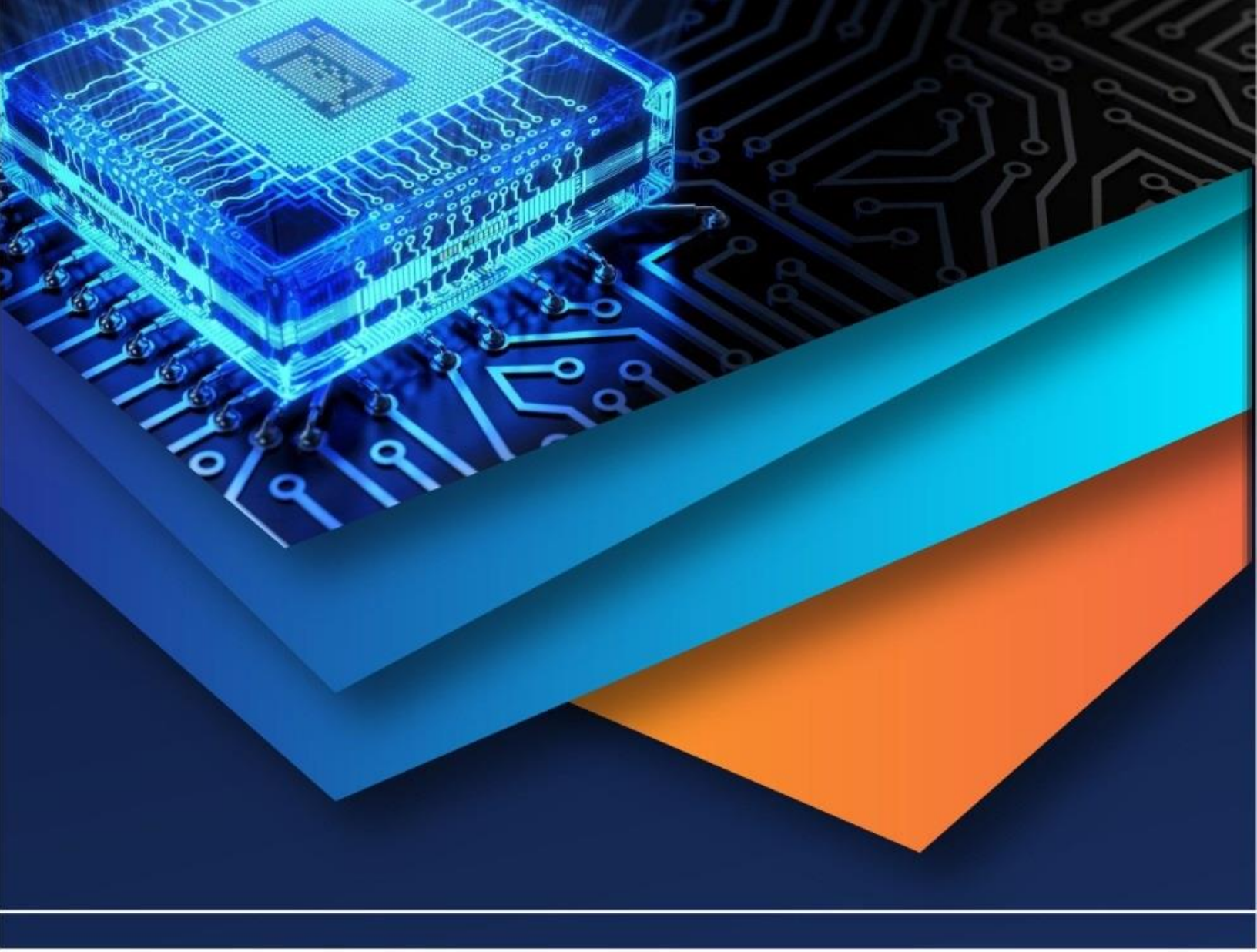

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